Suzaku Broad-Band Observations of the Hot Cluster of Galaxies RXJ1347–1145

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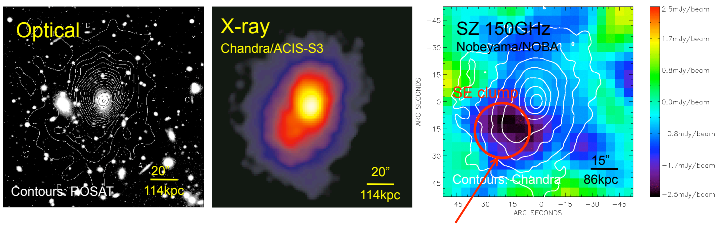
Abstract

We present the results from long *Suzaku* XIS+HXD observations of the most X-ray luminous galaxy cluster, RXJ1347-1145, at z=0.451. We study physical properties of the hot (~20 keV) gas clump in the south-east (SE) region discovered previously by the SZ effect observations, in order to understand the gas physics of a violent cluster merger. We also explore a signature of non-thermal emission using the hard X-ray data.

We find that the single-temperature model fails to reproduce the continuum emission and Fe-K lines measured by XIS simultaneously. The two-temperature model with a very hot component improves the fit, although the XIS data can only give a lower bound on the temperature of the hot component. We detect the hard X-ray emission in the HXD data in the 12-40 keV band at the 7σ level; however, the significance becomes marginal when the systematic error is included. With the joint analysis of the *Suzaku* and *Chandra* data, we determine the temperature of the hot gas in the SE region to be $kT_{ex}=23.5^{+4.9}_{-4.3}{}^{+6.0}_{-8.2}$ keV (90% statistical and systematic errors), which is in an excellent agreement with the previous SZ+X-ray image analysis (Kitayama et al. 2004). This is the first time that the X-ray analysis alone gives a good measurement of the temperature of the hot component, which is made possible by *Suzaku*'s unprecedented sensitivity to the hard X-ray band. These results strongly indicate that RXJ1347-1145 has undergone a recent, violent merger. The spectral analysis shows that the SE component is consistent with being thermal. We find the 3σ upper limit on the non-thermal flux, $F_{HXR} < 8\times10^{-12}$ erg s^{-1}cm^{-2} (12-60 keV), which provides a limit on the inverse Compton (IC) scattering of relativistic electrons off the CMB photons. Combining this limit with a recent discovery of the radio mini halo (Gitti et al. 2007), we find a lower limit on the strength of the intracluster magnetic field, $B > 0.02\,\mu$G.

1. RXJ1347–1145 at z=0.45 *"the most X-ray luminous galaxy cluster"*

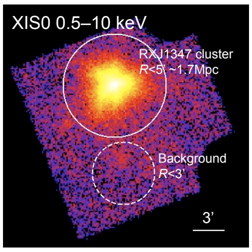


ASCA $L_{X,bol}$ ~ 2×10^{46} erg/s (Schindler et al 1997)

kT_{ex}>20 keV! (Kitayama et al. 2004)

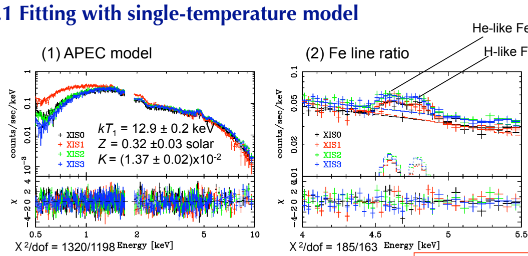
2. *Suzaku* observations

Date	Exposure [s] XIS	Exposure [s] HXD
2006–06–30	69661	56698
2006–07–15	79126	64922



3. XIS analysis: 0.5–10 keV

3.1 Fitting with single-temperature model

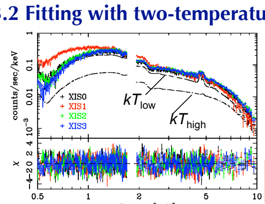


(He-like)/(H-like)=$1.05^{+0.29}_{-0.13}$

→ kT_2 = 10.4±1.0 keV

$kT_1 \neq kT_2$
→ Multi temperature plasma

3.2 Fitting with two-temperature model



kT_{low} = $9.7^{+0.7}_{-1.1}$ keV

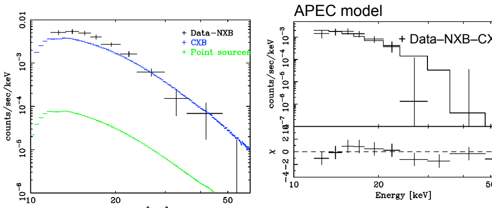
kT_{high} >32.5 keV

$Z_{low}=Z_{high}=0.33^{+0.03}_{-0.02}$ solar

X^2/dof = 1295/1207

In comparison to the single-temperature model, the fit is improved at the >99.99% CL by the F-test

4. HXD/PIN analysis: 12–60 keV



kT = $16.9^{+22.5}_{-7.8}{}^{+8.1}_{-8.3}$ keV

Z = 0.33 solar (fix)

K = $0.90^{+1.43}_{-0.47}{}^{+0.26}_{-0.53}$x10^{-2}

X^2/dof = 7.7/8

F = 3.1 ± 0.6 (± 3.6) x10^{-12} erg s^{-1}cm^{-2} in the 12–60keV

We detected hard X-ray emission in the 12–40 keV band at the 7σ level; but the significance becomes marginal when the systematic error of the background estimation (3%) is included.

5. XIS+HXD joint analysis

5.1 Modeling cluster average component with *Chandra*

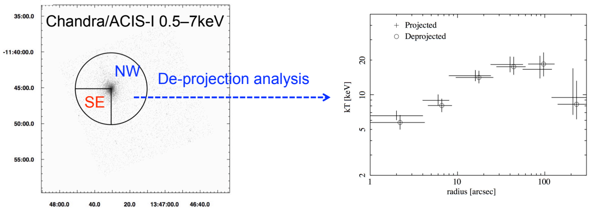


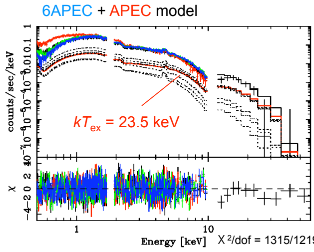
Table. "6APEC model", estimates of the deprojected temperature profile from the Chandra/ACIS-I data at the six annular bins in the NW region, which excludes the SE quadrant

Radius ["]	kT [keV]	Z [solar][a]	K[b]	χ^2/dof
0–4	5.74 (5.01 – 6.64)	0.47 (0.39 – 0.55)	0.97(0.92 – 1.02) × 10^{-3}	364.2/290
4–8	8.06 (7.10 – 9.20)		1.83(1.77 – 1.89) × 10^{-3}	
8–24	14.12 (12.61 – 16.08)		4.02(3.93 – 4.10) × 10^{-3}	
24–56	17.49 (14.95 – 21.26)		2.86(2.79 – 2.95) × 10^{-3}	
56–120	18.47 (14.49 – 23.18)		2.29(2.22 – 2.37) × 10^{-3}	
120–300	8.27 (6.15 – 13.16)		0.91(0.86 – 0.97) × 10^{-3}	

[a] The metal abundance is assumed to be common for all radial bins.
[b]The APEC normalization factor for each *spherical* shell

5.2 Temperature measurement of the SE clump

6APEC + APEC model



Suzaku XIS+HXD

kT_{ex} = $23.5^{+4.9}_{-4.3}{}^{+6.0}_{-8.2}$ keV

Z_{ex} = $0.38^{+0.03}_{-0.03}$ solar(*)

K_{ex} = $1.98^{+0.08}_{-0.09}{}^{+0.10}_{-0.14}$x10^{-2}

(90% CL; the first error being statistical and the second systematic)

Chandra ACIS-I

kT_{ex} = $31.1^{+24.1}_{-12.6}$ keV

Z_{ex} = $0.49^{+0.15}_{-0.15}$ solar(*)

K_{ex} = $1.47^{+0.21}_{-0.15}$ x10^{-2}

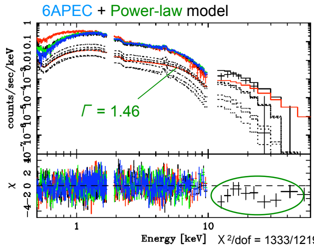
(90% CL; statistical only)

(*) The abundance was assumed to be the same for all the APEC components.

Suzaku's unprecedented sensitivity makes it possible to determine, for the first time, the temperature of such hot gas solely from the X-ray spectroscopy!

5.3 Constraint on non-thermal emission

6APEC + Power-law model



Suzaku XIS+HXD: Γ = $1.46^{+0.04}_{-0.04}{}^{+0.10}_{-0.04}$ ⟷ HXD only: Γ > 1.8 (90%)

The HXD spectrum is *softer* than 1.8, with the effective photon index being ~3. Thus it seems difficult to explain the SE excess emission with the non-thermal Power-law model

From the 6APEC + APEC + Power-law model fitting, the 3σ upper limit on the non-thermal emission is: F_{HXR} < 8 x 10^{-12} erg s^{-1} cm^{-2} in the 12–60keV band.

6. Discussion

6.1 Properties of the extremely hot gas

From the analysis of the *Suzaku* XIS+HXD spectra, we have found that the temperature of the SE clump is $kT_{ex}=23.5^{+4.9}_{-4.3}{}^{+6.0}_{-8.2}$ keV (90% statistical and systematic erros). This is an excellent agreement with the previous measurement by Kitayama et al. (2004), 28.5 ±7.3 keV (68%; statistical only).
We estimate the gas density and the gas mass by simply assuming that the extremely hot gas is uniformly distributed within a sphere of R = 25" (because the excess is present in 10"< r <60"). From the measured K_{ex}, we obtain $n_{e,ex}$= (1.6 ± 0.2)x10^{-2} cm^{-3} and $M_{gas,ex}$= (5.6 ± 0.8)x10^{12} $M_\odot$. We also find that the SE clump exhibits the temperature and the density that are higher than the ambient gas in the same radial bins by factors of 1.6 and 2.4, respectively. Thus the excess hot component is over-pressured, and such a region is expected to be short-lived (~0.5 Gyr; Takizawa 1999). The gas properties can be explained by a fairly recent (within the last ~0.5 Gyr), bullet-like high velocity (~4500 km/s) collision of two massive (5x10^{14}$M_\odot$) clusters. Our results support this merger scenario, solely from the X-ray spectroscopic data without help of the SZ data.

6.2 Estimation of the magnetic field

The non-thermal hard emission is produced via the IC scattering of relativistic electrons off the CMB photons, and the same electrons (with the same Lorentz factor, γ) also produce the synchrotron radiation. Then one can relate the magnetic field strength in the ICM, the power in IC, the power in synchrotron, and the energy density of CMB photons via $P_{IC}/P_{syn} = U_{CMB}/(B^2/8\pi)$. We find the upper limit on the IC flux density, $S_{IC}<0.11\,\mu$Jy for electrons with γ=5000 (or the IC emission energy of 12 keV). A recent discovery of the radio mini halo by Gitti et al. (2007) yields $S_{1.4}$=25mJy at 1.4GHz. We also assume that synchrotron flux density is a power-law, $S_{syn}\propto\nu^{-1/2}$. From these numbers, we obtain a lower limit on the magnetic field as $B > 0.02\,\mu$G. This limit, though weak, is consistent with typical values found in other clusters, B~0.1–1 μG (e.g., Rephaeli et al. 2008).

See Ota et al. astro-ph/08050500 for more details.

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